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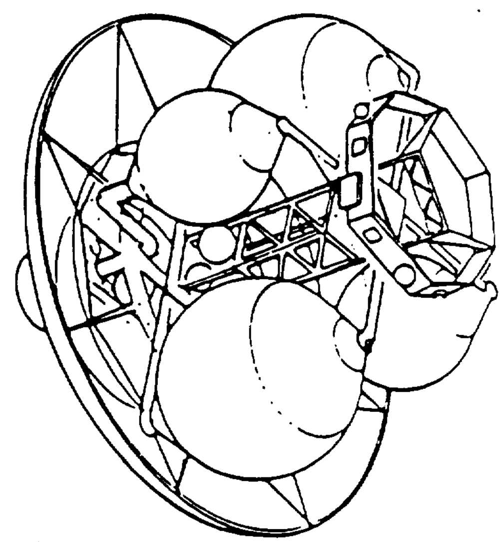
Volume I-A

Executive Summary Supplement

Orbital Transfer Vehicle Concept Definition And System Analysis Study 1986



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ORBITAL TRANSFER VEHICLE
CONCEPT DEFINITION AND SYSTEM ANALYSIS STUDY

VOLUME I-A
EXECUTIVE SUMMARY SUPPLEMENT

April 1987
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FOREWORD

This final report, Volume IA-Executive Summary Supplement, was prepared by Martin Marietta Denver Aerospace for NASA/MSFC in accordance with amendment 5 to contract NAS8-36108. The entire study was conducted under the direction of NASA OTV Study Manager, Mr. Donald R. Saxton, during the period from July 1984 to October 1986. This final report is arranged into nine volumes:

Volume I	Executive Summary	
Volume IA	Executive Summary Supplement	
Volume II	OTV Concept Definition and Evaluation	
	Book 1	Mission and System Requirements
	Book 2	OTV Concept Definition
	Book 3	Subsystem Trade Studies
	Book 4	Operations
Volume III	System and Program Trades	
Volume IV	Space Station Accommodations	
Volume V	Work Breakdown Structure and Dictionary	
Volume VI	Cost Estimates	
Volume VII	Integrated Technology Development Plan	
Volume VIII	Environmental Analyses	
Volume IX	Study Extension Results	
Volume X	Aerocapture for Manned Mars Missions	

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1.0 OTV EXTENSION STUDY OVERVIEW

This activity is an extension of the Orbital Transfer Vehicle Concept Definition and System Analysis Study that was initially awarded in July, 1984. The original study established the OTV design, operations and basing concepts that were most effective in the situation where: 1) Shuttle capability is growing aggressively; 2) Space Station is being phased in; 3) Decisions are to be justified by a conservative mission model; and 4) Any large lift capability development is to be justified by high earth orbit transport benefits. This extension scenario establishes changes to the OTV program that would result from: 1) A wide variety of aggressive mission models; and 2) A large cargo vehicle capability whose DDT&E is not charged to the OTV program. Thus the extension study opens the scope of potential recommendations by introducing a variety of ambitious programs, and by making the large cargo vehicle recommended by the Space Transportation Architecture Studies available at no acquisition cost to the OTV program. It is a further objective of the extension study to evaluate the sensitivity of OTV program recommendations to scenario variations such as different mission models, different launch vehicle availability, and different space station availability.

We conducted this study in two primary parts, the first culminating in the midterm review and the second in the final review and this final report. The activities conducted in the first part, as shown in Figure 1, were primarily those that could be accomplished without a definition of the

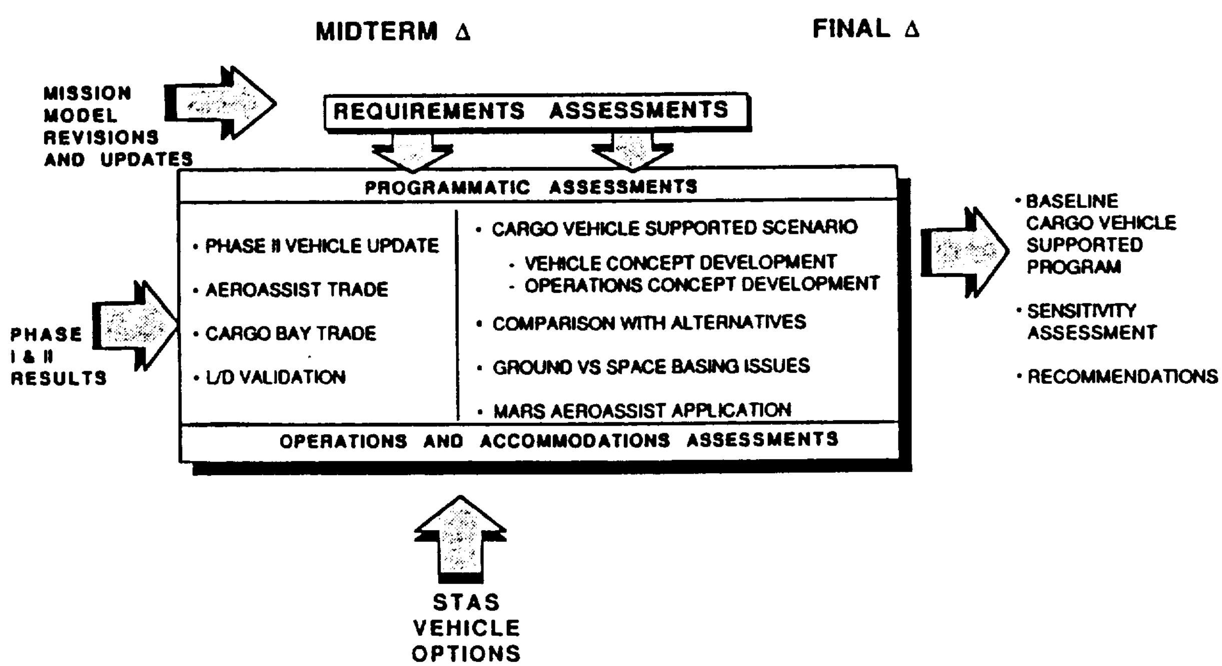


Figure 1 OTV Study Extension Approach

large cargo vehicle. When this definition became available from the STAS studies after the midterm review, the activities that were dependant on this information were conducted. These primarily delved into the effect of the availability of the large cargo vehicle on the preferred OTV program. Requirements assessments were ongoing throughout the whole study, as the definition of mission requirements is always in a continuous state of change. Operations and accommodations assessments were also continuous, and supported all study activities as required. Final extension study output includes definition of a baseline cargo vehicle supported OTV program and an assessment of the sensitivity of this baseline program selection to mission model options, to launch vehicle availability, and to variations in the space station development scenario. Finally, recommendations relative to the OTV development activities that should be followed were made.

2.0 SUMMARY OF EXTENSION STUDY

2.1 EXTENSION STUDY OBJECTIVES

The purpose of this extension to the OTV Concept Definition and System Analysis Study was to improve our understanding of the OTV program that will be most beneficial to the nation in the 1995 - 2010 timeframe. This activity built on the effort completed in prior study effort. It investigated the implications of the missions defined for, and launch vehicle defined by, the Space Transportation Architecture Study (STAS). It delved more deeply into selected concerns.

The key new mission requirements identified for STAS reflect a desire for greater early capability and more ambitious growth capability. The four key technical objectives and related issues addressed are: 1) To update and expand prior study activities; 2) To investigate the impact of a Large Cargo Vehicle (LCV); 3) To optimize OTV operations and space based OTV accommodations; and 4) To investigate program alternatives applicable to different use scenarios. We have updated the OTV program approach previously selected in the area of vehicle design. New mission requirements, evolving space station definition, and proposed new launch vehicles were evaluated. We enhanced our analyses of selected areas including aeroshield design, proximity operations and the balance of EVA and IVA operations used in support of the OTV at the space base.

These activities led to an improved definition of an OTV program that should receive favorable consideration for an early new start. An important aspect of this effort was developing a thorough understanding of the sensitivity of the OTV program selection to changes in use, economic environment and technology development. We conducted sensitivity studies to establish how the OTV program should be tailored to meet changing circumstances.

2.2 CONCLUSIONS - RESULTS

This extension study has assessed the impact that the existence of a Large Cargo Vehicle and a variety of aggressive mission models would have on the preferred Orbital Transfer Vehicle program. We find that the low Earth-to-Orbit transportation cost provided by the LCV, nominally $70M to deliver 150,000 pounds to low earth orbit (LEO), is a significant benefit to carrying out any high earth orbit program. We prefer an OTV program supported by a large cargo vehicle whose acquisition cost is not charged to the OTV program. We find that an aeroassisted reusable OTV remains the preferred design approach in the stipulated LCV, aggressive mission model scenario. An OTV designed to operate from the LCV is different than one designed to be supported by the existing Orbiter. We prefer a three in-line engine configuration that achieves engine-out capability with a short configuration, and provides a convenient growth path from unmanned ground based operations to manned space based operations. We find a two vehicle fleet provides cost effective support of the nominal civil and DoD mission models defined for use by the Space Transportation Architecture Study (STAS). The ground based configuration should not be man-rated, and should be used through the operational period. The larger space based OTV should support all GEO and lunar missions, which encompass all man-rated requirements.

A space based OTV capability is key to the operation of advanced missions such as the lunar base and manned Mars initiatives that have been suggested by the National Commission On Space. It is also highly beneficial to the operation of the manned GEO missions that are expected to begin shortly after the turn of the century. Our analyses show that the space based OTV cost per flight will be 10 % lower than ground based cost per flight. We believe it is possible for the space based OTV to be economically competitive with a totally ground based program on a discounted life cycle cost basis, but it is necessary to take care in constituting a space based program and to credit all the potential benefits of the space based program to achieve this goal. The development cost of achieving a space based capability must be controlled. Cost sharing of facilities with the OMV program is necessary, and the development of an efficient propellant storage facility that is matched with Space Station reboost system propellant requirements is encouraged. We find that the low cost of the LCV tends to reduce the economic advantage of space basing over ground basing, in comparison with the advantage that exists in a scenario supported completely by the existing Orbiter system enhanced by an Aft Cargo Carrier based propellant scavenging system. In both cases, the operational economy of space basing stems from more efficient utilization of the launch vehicle. We found that most OTV propellant requirements could be provided by scavenged propellants in the Orbiter supported (low flight rate) scenario, and that the cost advantage of scavenged propellants over Orbiter transported propellants was very large. In the case of the lower cost LCV, the cost advantage of "hitchhiked" propellants was less, but still significant. A corollary advantage of space basing is that the more efficient utilization of the launch vehicle results in fewer Earth to LEO launches and consequent lower use of a reusable, or partially reusable, launch vehicle. Launch vehicle replacement cost is thus reduced. When these cost advantages are incorporated in to the economic comparison of ground and space based OTV programs, they become very close on a discounted life cycle cost basis, and the advantage lies with the space based concept in constant year dollars.

We found further advantages to space basing OTV that make development of this capability desirable beyond its potential for lower future operational cost:

1) Space basing assures access to GEO by providing an alternative transfer capability;

2) Space basing decouples launch and transfer activity , enabling GEO payload launch to LEO by foreign/commercial vehicles and yielding greater mission flexibility;

3) Fewer ground launches are required, reducing the risk of launch area contamination and the possibility of catastrophic accidents;

4) Space station based GEO transfer operations enable reduced payload losses through checkout, burn-in, and repair at LEO -- which will lead to lower insurance rates;

5) A space based operation will reduce vulnerability to some low technology threat classes.

We found that the high traffic mission scenarios suggested by the strategic defense initiative and nuclear waste disposal justify adding a small OTV that is efficiently tailored to support these mission options. We found that the aggressive expansion of the civil mission scenario into very large GEO spacecraft and advanced lunar base support did not justify development of a very large OTV configuration. Rather, it proved more economical to use multi-stage configurations comprised of smaller OTVs, or spacecraft segmentation. We also found an ancillary advantage of space basing in the fact that it tends to desensitize the cost of HEO space operations to the cost of the launch vehicle.

2.3 RECOMMENDATIONS

We recommend that an unmanned, ground based OTV capability be developed in the mid 1990's, and that this capability be retained throughout the foreseeable future. Development of this vehicle as an aeroassisted reusable vehicle is economically justified, even in the most modest projected mission scenarios. We believe that, even though it is difficult to justify on a discounted life cycle cost basis, the lower operational cost of space based OTV missions and the ancillary operational benefits justify investment in space basing. We recommend directing further Phase A effort at identifying an initial OTV that will be useful whether or not a large cargo vehicle program is initiated in the near future, and one that has a good growth path to space based capability. We believe the key to meeting this objective is to develop a concept that can fly in an Aft Cargo Carrier or a large cargo vehicle with minimal design penalty. After this concept is delineated, an extended Phase B should optimize the concept, and a full scale development directed at achieving a mid 90's initial operational capability should be undertaken. The scheduling of the full capability , space based OTV development program depends on the progress of the Space Station program, but we recommend undertaking this development as soon as possible.

3.0 MISSION AND LAUNCH VEHICLE DRIVEN REQUIREMENTS

The STAS mission model defines four program options for both the civilian and the DoD program. Our studies were ground ruled to deal with five of the 16 possible combinations as shown in Figure 2. Scenario 2, representing the baseline civil and the normal growth DoD options was used for all design decisions and recommendations. The impacts of the other Scenario requirements summarized were studied as sensitivities. The major differences from Scenario 2 are as follows:

- Scenario 1 has no manned or lunar missions. Its traffic level is roughly equivalent to the Revision 8 Nominal Model that was used in the 1984/85 portion of this study.

- The OTV portion of Scenario 3 is changed little from Scenario 2, but does have three additional large planetary missions.

- Scenario 4 has a large increase in DoD traffic to low altitude, mid-inclination orbits.

- Scenario 5 reflects the new Lunar Base and Manned Mars initiatives suggested by the National Commission on Space, and a large number of nuclear waste disposal missions.

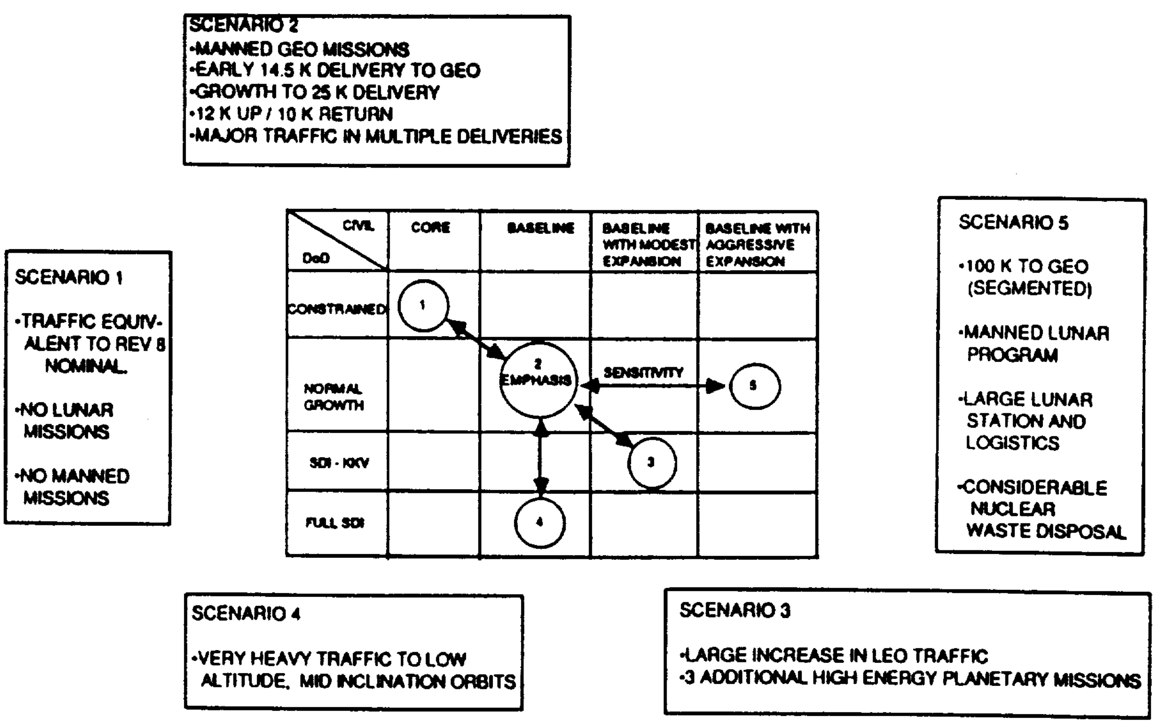
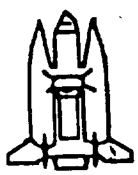
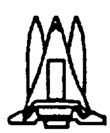


Figure 2 Revision 9 Mission Model Characteristics

The major characteristics of the three launch vehicle options considered in the extension study, the shuttle, a large cargo vehicle and STS II, are summarized in Figure 3. Nominal payload capability, cargo bay size and cost are shown -- as are variations considered from a sensitivity point of view. The nominal availability date for the large cargo vehicle is 1995, the STS II availability date is 2002. Consideration is also given to a sensitivity scenario where advanced launch vehicle availability dates are delayed. Note that, unlike the groundrule used during the first part of this study, these capabilities are available without sharing the development and build cost required to acquire them.

	NOMINAL CHARACTERISTICS	VARIANCE
 STS	65,000 LB TO LEO 15 X 60 FT R/T $90.8M / FLT @ 20 / YR (ETR)	ACC UP @ $2.4M / FLT ($171M DDT&E)
 LCV	150,000 LB TO LEO 25 X 90 FT UP NO RETURN 1995 EARLIEST IOC $70M / FLT @ 20 / YR *	100 - 200 KLB (22 - 33) X (90 - 100) UP RETRIEVE @ $15M Δ/flt ? $50M - $85M
 STS II	65,000 LB TO LEO 15 X 60 FT R/T 2002 EARLIEST IOC $20M / FLT @ 45 / YR *	40 - 80 KLB (15 - 23) X (30 - 70) FT R/T ? $20M - $30M

* NO DDT&E COST TO OTV PROGRAM

Figure 3 Launch Vehicle Options

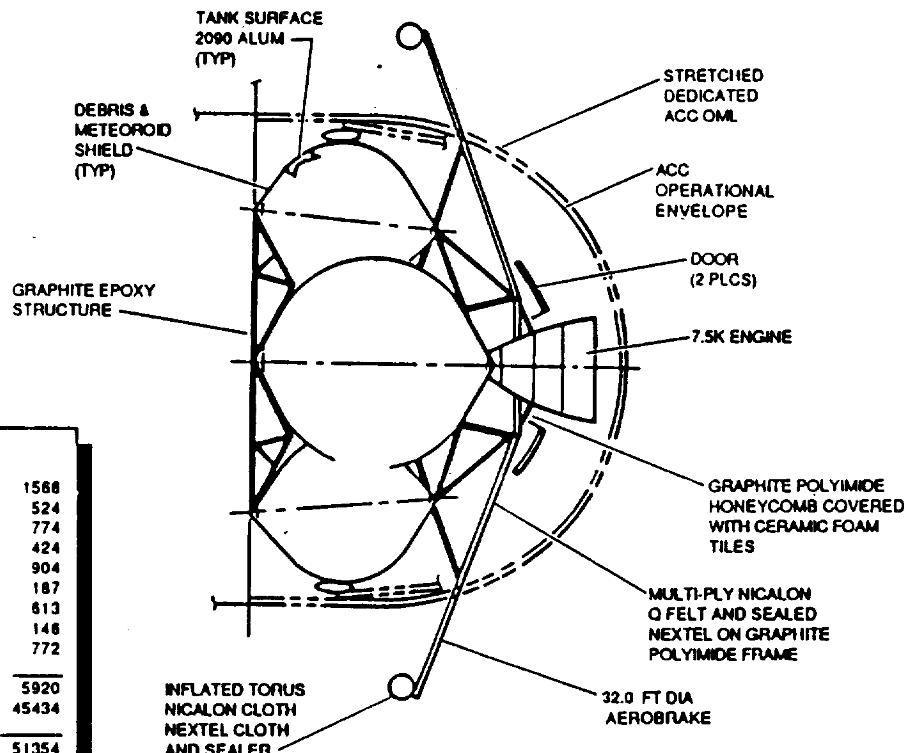
4.0 STS BASED CONCEPT DEVELOPMENT

The initial portion of the extension to the Orbital Transfer Vehicle Extension Study was used to update Phase 1 vehicle designs to reflect changing mission and system requirements, to conduct a common basis trade of candidate aeroassist devices, and to conduct a trade study to identify the preferred STS Cargo Bay OTV design concept.

4.1 UPDATE OF PHASE 1 VEHICLES

Our 1984/85 studies established that the Revision 8 Low Mission Model justified an OTV fleet comprised of two vehicles: An unmanned, ground based, cryogenic OTV designed to be lifted to orbit in the Aft Cargo Carrier; and a man-rated, cryogenic OTV permanently based at the Space Station. Both configurations used a four-propellant-tank concept. Since the ground based configuration was not man-rated, it used one main engine. This engine incorporated new technology, but pressed it only to a performance level of 475 seconds specific impulse to reduce development risk. This same engine is used in a dual installation in the space based configuration. The propellant capacity of the ground based configuration was 45,000 pounds. In the Revision 8 scenario, the space based configuration must retrieve a 7500 pound manned capsule. Its 55,000 pound propellant capacity and its 44 foot aerobrake diameter were sized to meet this requirement. Both configurations used composite structure -- graphite epoxy for the cool structure and graphite polyimide for the hot aerobrake support structure. The selected program was justified by the Revision 8 Low Mission Model. The IOC for the ground based system was 1984, and the space based IOC was 1999. This scenario justified development of the ACC scavenging system rather than a new large capability propellant tanker. The space based vehicle, although not initially man-rated, had all the equipment installed that was required to make this possible. The only additional requirement to achieve man rating was validated flight experience, which was to be gained during the early unmanned years of space based operation.

Figure 4 shows an updated version of the ground based OTV recommended by the 1984/85 study effort. Updates were required to meet the improved definition of the low altitude debris model currently available, and to meet the vibration environment anticipated in the ACC. The resulting updates are: Beefed up structure to provide a margin for possible load increases and the ACC vibration environment anticipated; And the addition of debris shielding to the propellant tanks. We also redesigned the aerobrake to more faithfully implement the blunted cone aerobrake shape proven on the Viking Mars landers. In the initial design, aerobrake ribs were curved to fit more readily into the dedicated ACC. In the updated design, the fold is moved outboard to enable the incorporation of straight ribs. The resulting weight increases are reflected in the figure.



WEIGHT	
AEROBRAKE	1566
TANKS	524
STRUCTURE	774
ENVIRONMENTAL CONTROL	424
MAIN PROPULSION	904
ORIENTATION CONTROL	187
ELECTRIC SYSTEMS	613
G,N & C	146
CONTINGENCY 15%	772
DRY WEIGHT	5920
PROPELLANTS, ETC.	45434
LOADED WEIGHT	51354

Figure 4 Updated Ground Based Cryogenic OTV

The primary updates to the space based cryogenic OTV concept developed in the 1984/85 study effort are with regard to overall sizing and additional meteoroid and debris protection. The revision in overall sizing results from the updated mission model being used for this study (Rev. 9). This mission model requires a 74 Klb propellant capacity OTV to perform the 12,000 pound up, 10,000 pound return manned GEO Sortie and GEO Shack Logistics missions. Therefore, the vehicle has been scaled up in size from the 55 Klb propellant capacity required in the earlier effort. The revised configuration and associated weight statement is shown in Figure 5.

WEIGHT	
AEROBRAKE	1800
TANKS	1025
STRUCTURE	1370
SUPPORT (ASE)	114
ENVIRONMENTAL CONTROL	730
MAIN PROPULSION	1288
ORIENTATION CONTROL	265
ELECTRIC SYSTEMS	533
G, N & C	160
CONTINGENCY 15%	1093
DRY WEIGHT	8378
PROPELLANTS, ETC.	74015
LOADED WEIGHT	82393

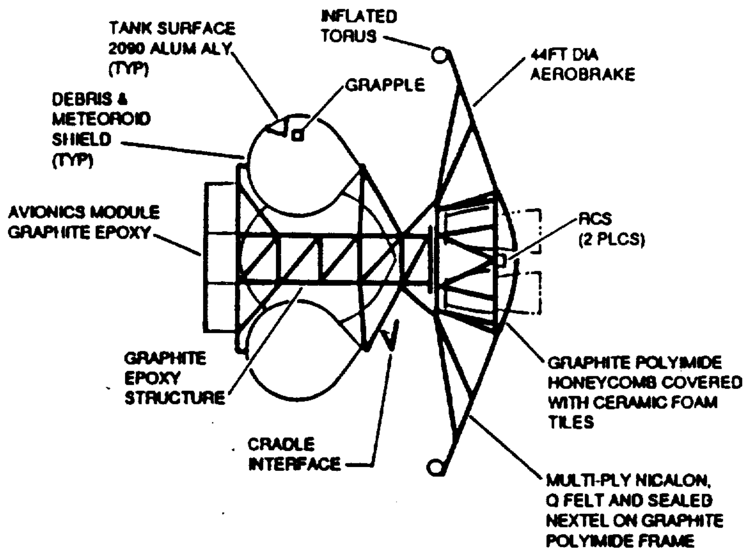


Figure 5 Updated Space Based Cryogenic OTV

4.2 AEROASSIST TRADE

A comprehensive, common basis, design comparison was developed for the three basic aeroassist concepts under consideration. The concepts are illustrated in Figure 6 -- the rigid aerobrake, the flex aerobrake, and the ballute. The design evaluations were completely comparable, and used Martin Marietta estimating factors throughout. The design was selected to perform the maximum GEO round trip mission as defined early in the extension study -- a 13, 300 pound up, 11,300 pound down mission with a 23 foot length. This payload is slightly heavier and longer than the one defined by MSFC after the midterm review (12K up, 10K down and 15 feet long). It still suffices on a common reference condition, but does drive the ballute design to a larger diameter to achieve aerodynamic stability. Selection criteria included program cost, vehicle performance, growth potential and flexibility.

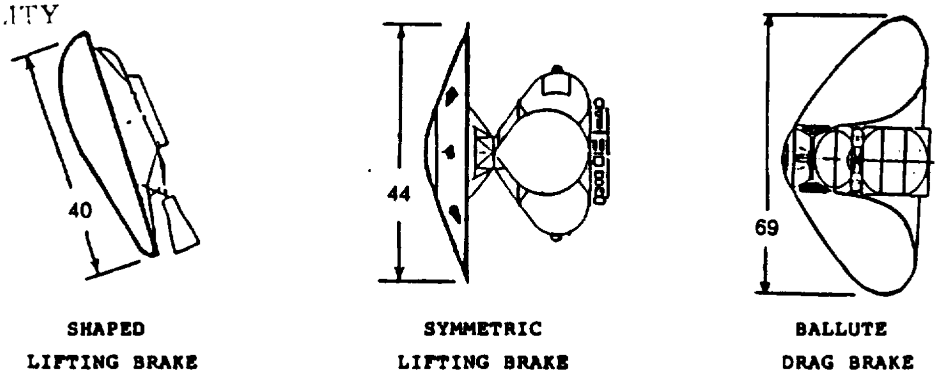


Figure 6 Aerobrake Candidates

Figure 7 shows the weight and cost data derived for each of the space based OTV concepts considered during this trade study. The results indicate that production and development costs cannot be used as significant discriminators in comparing the vehicle concepts. The major cost item is the operational cost of providing propellant for the OTV and maintaining the vehicle in space. The propellant required is primarily a function of the vehicle dry weight shown. The data shows that the ballute is only effective with the 1500°F backwall temperature -- which could have an impact on retrieval spacecraft thermal protection. With the 1500°F backwall temperature, the ballute is competitive with the rigid brake. The flex brake design at a L/D = 0.12 is the lightest. Included

RIGID BRAKE WEIGHTS

AEROBRAKE	1794
TANKS	396
STRUCTURE	3350
SUPPORT (ASE)	272
ENVIRONMENTAL CONTROL	185
MAIN PROPULSION	1288
ORIENTATION CONTROL	265
ELECTRIC SYSTEMS	533
G, N&C	160
CONTINGENCY (15%)	1236
DRY WEIGHT	9479
PROPELLANTS, ETC	74000
LOADED WEIGHT	83479

$\lambda = 0.886$

BALLUTE WEIGHTS

AEROBRAKE	1999	3917*
TANKS	1251	
STRUCTURE	1033	
SUPPORT (ASE)	272	
ENVIRONMENTAL CONTROL	598	
MAIN PROPULSION	1288	
ORIENTATION CONTROL	265	
ELECTRIC SYSTEMS	533	
G, N&C	160	
CONTINGENCY (15%)	1230	
DRY WEIGHT	9429	11153*
PROPELLANTS, ETC	74000	
LOADED WEIGHT	83429	

* For 600° Backwall Temp

$\lambda = 0.887$ (0.909 w/o brake)

FLEX BRAKE WEIGHTS

AEROBRAKE	1034
TANKS	422
STRUCTURE	2180
SUPPORT (ASE)	272
ENVIRONMENTAL CONTROL	203
MAIN PROPULSION	1288
ORIENTATION CONTROL	265
ELECTRIC SYSTEMS	533
G, N&C	160
CONTINGENCY (15%)	1074
DRY WEIGHT	8231
PROPELLANTS, ETC	74015
LOADED WEIGHT	82246

$\lambda = 0.900$ (0.920 w/o brake)

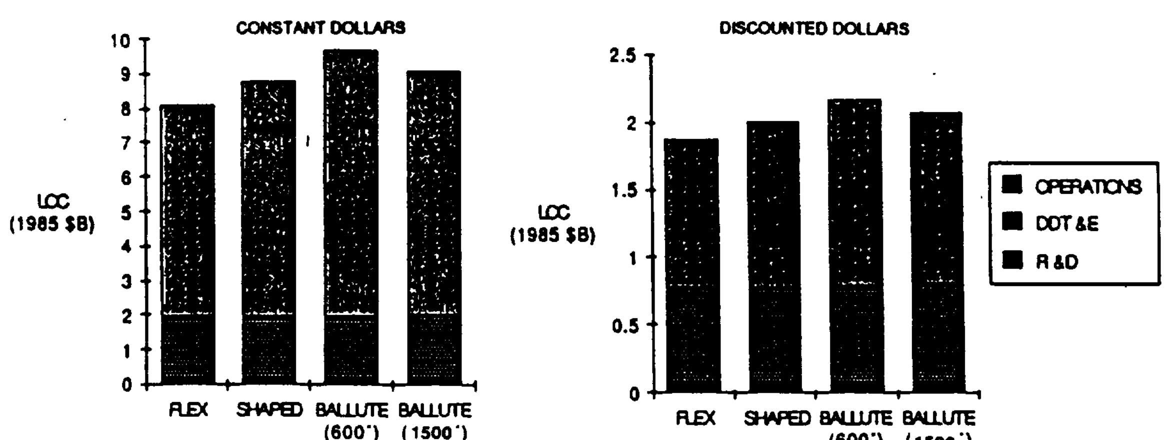


Figure 7 Aeroassist Evaluation Results

in the operational costs are the servicing operations of removing and replacing the aeroassist devices on each of the OTV concepts. This particular operation is the only discernible difference in space based maintenance of the three concepts and is still relatively minute in comparison to the propellant launch costs.

The preferred flex brake design is summarized in Figure 8. The central 14.5 foot diameter is fabricated using shuttle tiles set on a graphite polyimide honeycomb cone with engine doors incorporated in it. This structure forms a base for the graphite polyimide ribs that support the flexible portion. The flexible portion is a multi-ply Nicalon faced Q felt and NEXTEL blanket which is sealed with RTV sealant on the cool (600° F) inside surface. The ribs are glued to the blanket to provide torsional stiffness. An inflated torus provides required curvature at the periphery of the brake, and stiffens the edge. As noted, this is the lightest design approach to a low L/D aerobrake.

This flexible material is in a developmental stage, and its operational characteristics are not well understood. In lieu of definitive data, its operational life has been estimated at five uses -- shorter than the rigid brake at 20 uses, but longer than the single mission life of the ballute which must be repeatedly flexed during use. The data being developed by the Ames Research Center is promising, but needs to be pursued further. Therefore, our recommendation -- use the concept but continue to support the materials technology program.

- FLEX BRAKE PROVIDES LIGHTEST, LEAST LCC APPROACH
- FLEX MATERIAL IS DEVELOPMENTAL AND INVOLVES SOME TECHNICAL RISK
- RECOMMENDATION
  - INCORPORATE FLEX BRAKE IN CONCEPT
  - PURSUE MATERIAL TECHNOLOGY DEVELOPMENT

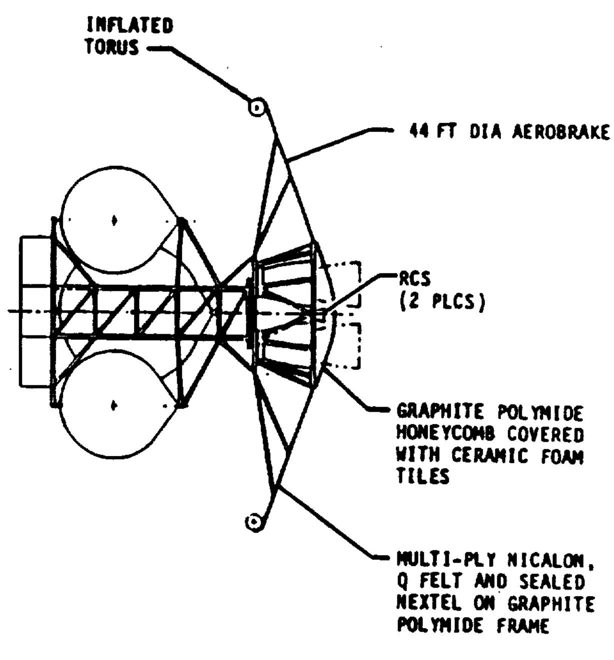
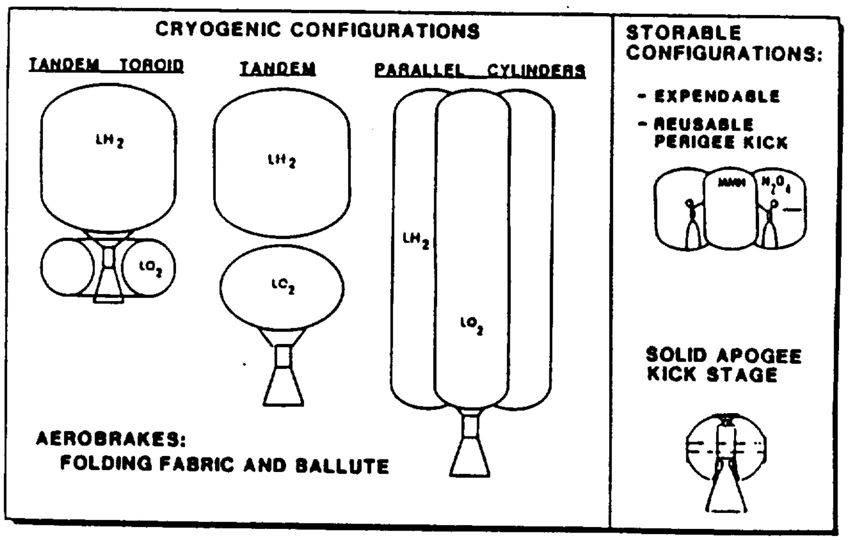


Figure 8 Recommended Aeroassist Concept

4.3 CARGO BAY VEHICLE TRADE

The concepts considered in the cargo bay trade study include various configurations of storable and cryogenic propellant vehicles. Cryogenic propellant concepts were sized for the three tankage configurations shown in Figure 9. In addition, the concepts were sized for two aerobrake types (ballute and flexible folding fabric brakes) for each of the tankages. Each of these cryogenic concepts is intended to be fully reusable with the exception of the aerobrakes which may be replaced after each mission.



BASIS FOR COMPARISON

- THE 35 GROUND BASED MISSIONS IN THE LOW REV 8 MODEL
- VEHICLE SIZED FOR 15,000 LB DELIVERY

CRITERIA

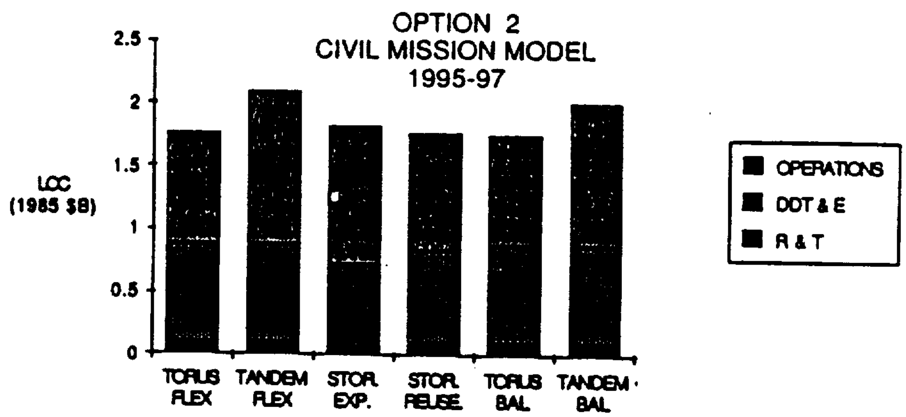
- LAUNCH COSTS
- FLIGHT OPNS COSTS
- FLEXIBILITY
- DEVELOPMENT COSTS
- PRODUCTION COSTS

Figure 9 Cargo Bay Options

The storable propellant concepts include a liquid expendable stage and a reusable liquid perigee stage with a solid apogee kick stage. These were conceived to compare lengths and total costs with the most attractive cryogenic configurations.

Cost comparisons were made on the basis of the 35 ground based missions in the low Revision 8 mission model. Vehicles were sized to perform a 15,000 pound GEO delivery mission (slightly over the 14.5 Klb mission that appears early in the Revision 9 mission model). This sizing provides a stage that can perform all early model missions, even though the launch mode could be complex if STS payload growth is not achieved. The criteria used to select between these options includes the cost parameters indicated in Figure 9, and consideration of the flexibility the configuration provides for growth to larger energy applications. Launch cost is strongly influenced by configuration length and the impact it has on the STS charge algorithm in non-weight-limited manifest.

Figure 10 shows the selection data for the ground based OTV candidates. Gross weight and length data reflect vehicle sizing to perform a 15,000 pound delivery mission; adequate to support near term Revision 9 model delivery requirements. The primary evaluation criteria of interest is cost associated with STS flights for OTVs and their payloads. Length of each concept in the cargo bay is the large driver in determining STS flights required when vehicle gross weight is not limited. This was assumed to be the case in determining the number of flights required shown in Figure 10. Although production and development costs may not be significant in terms of decision making, they are accounted for.



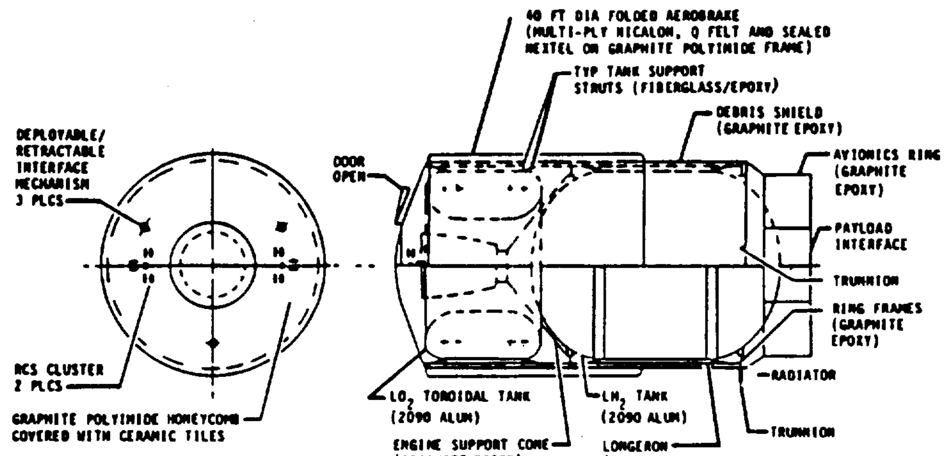
	TORUS FLEX	TANDEM FLEX	STOR. EXP.	STOR. REUSE	TORUS BAL	TANDEM BAL
GROSS WT (WT)	67.3	68.7	77.5	82.9	68.3	67.8
LENGTH (FT)	26.0	33.5	11.5	24.0	26.5	31.3
FLIGHTS	31	42	23	28	31	40

Figure 10 Evaluation Criteria Summary (Discounted $)

Consideration must also be given to overall flexibility for flying higher energy missions as well as adapting to the possible new generation booster vehicles. In addition, a smooth transition from a ground based vehicle to space based is a desirable feature, providing that this growth path is cost effective for a given vehicle concept.

Torus flex, torus ballute, and the two storable configurations are competitive cost options. The storables were eliminated because they were too heavy to fly in any version of STS anticipated. While the cost of the ballute design is competitive, we selected the flex brake concept because of its superior characteristics relative to the space based application. We recognize the torus tank concept is difficult to grow to a 2 engine man-rated configuration. This ground based vehicle need not be man-rated. Its cost advantage over the tandem tank configuration is sufficiently important to allow a concept change when transitioning to manned, space based operation.

Figure 11 shows the selected cargo bay ground based OTV, which is capable of delivering 15 Klb to GEO from STS deployment in LEO. The concept is attractive because of its short length (compared with other cryogenic configurations) and high performance.



WEIGHTS	
AEROBRAKE	1148
TANKS	487
STRUCTURE	945
ENVIRONMENTAL CONTROL	220
MAIN PROPULSION	904
ORIENTATION CONTROL	187
ELECTRIC SYSTEMS	613
G,N&C	156
CONTINGENCY (15%)	700
DRY WEIGHT	5360
PROPELLANTS, ETC	45434
LOADED WEIGHT	50794

CONCERNS

- HOW TO MANRATE
- HOW TO GROW TO SPACE BASED 25 KLB DELIVERY

Figure 11 Recommended Concept - Cargo Bay OTV

The main contributor to the short length of the vehicle is the incorporation of a toroidal LO_2 tank which surrounds the main engine package. Emphasis on short length while maintaining high performance (maximum payload capability at minimum gross weight) is the reason for the selection of this concept. Stage length plus ASE should not exceed 30 ft (according to the mission model assessment) in order to minimize STS launch costs. In other words, 30 ft payload capability along with sufficient performance are the major characteristics desired from a cargo bay OTV. This stage meets these criteria with its 26.5 ft length and packaging characteristics with its ASE.

Two growth concerns exist with this concept -- how to install two engines for man rating, and how to achieve growth to the ultimate requirement of a 25,000 pound delivery. We believe the growth from the ACC configuration to the ultimate space based vehicle is to be preferred over growth from a cargo bay vehicle.

5.0 CARGO VEHICLE BASED OTV CONCEPT DEVELOPMENT

5.1 ROLE OF REUSABILITY

The first step in evolving the preferred cargo vehicle based OTV was to review the thought process that established aeroassisted-reusable as the preferred option in the STS supported use scenario, and and to apply it to the situation where a large unmanned cargo vehicle is available. Figure 12 summarizes the trades conducted to assess the role of reuse in the large cargo vehicle era.

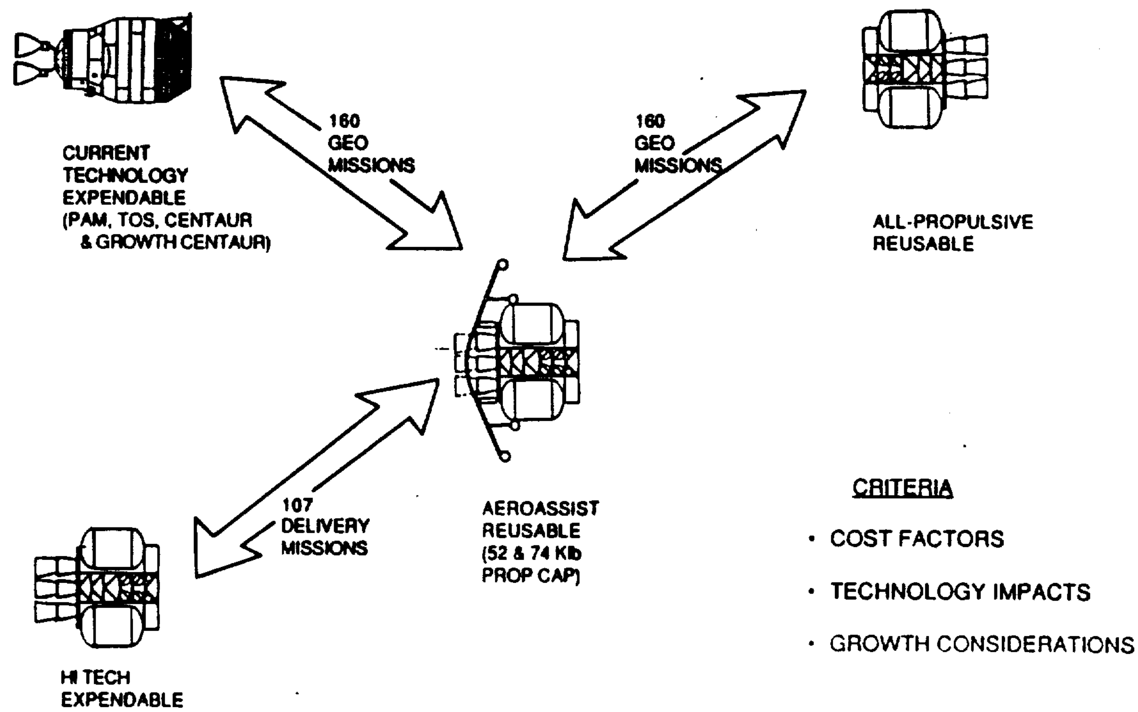


Figure 12 Reuse Mode Options (Cargo Vehicle, Ground Based)

The current technology expendable family, a new all-propulsive reusable concept, and a new high technology expendable concept were compared with the aeroassisted reusable approach. The current technology expendable and all-propulsive reusable concepts were compared on the basis of the 160 civil GEO missions in the Scenario 2 mission model. These missions included large spacecraft retrieval missions, and were judged to be most representative of the traffic targeted for OTV. DoD missions and non-GEO missions increase the use base of OTV, and would tend to make the new aeroassist technology more readily justifiable. Since the basis used supported aeroassist, we felt a larger mission sampling could only reinforce our conclusion.

We also investigated the general parameters associated with development of a high technology expendable. Since we did not have the resources to conceive and thoroughly investigate the high tech possibilities, we settled for establishing the cost parameters that would have to be achieved to make this approach a winner.

The criteria used to discriminate between options is identified in Figure 12. Cost factors include front end and operational cost, as well as life cycle cost viewed in constant and discounted dollars. Technology and growth implications were also subjectively evaluated. We feel that developmental concept that yields lowest cost per flight and breaks even in discounted dollars should be considered a highly desirable approach.

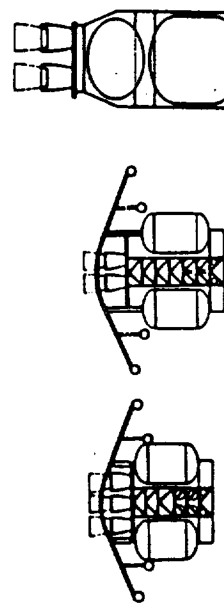
Comparison of the three concepts identified with a two member family of aeroassisted vehicles shows the following: (1) The current technology upper stages, while saving approximately $1B in development cost, require that 292 stages be built and expended, require that 130 more flights be manifested on a launch vehicle, and lose in life cycle cost by $13.8B in constant year dollars ($1.7b in 10% discounted dollars); (2) The all propulsive approach, while saving approximately $0.2B in development cost, costs $24M more per flight to operate, and loses in life cycle cost by $2.2B in constant year dollars, ($0.2B in 10% discounted dollars); (3) The high tech expendable approach has to achieve a build cost of $32M per article to be competitive. This comparison was based on weights associated with light weight design techniques. Should lightweight design be sacrificed for low cost design, this target cost would grow rapidly because of increased propellant logistics requirements. Two ways this goal could be achieved are: Through a strong learning curve developed over a 15 year buy; And through an as yet unidentified technical breakthrough in design or manufacture. It is not clear that either possibility can be achieved.

The aeroassisted reusable approach is to be preferred over expendable and all-propulsive reusable operational modes in the cargo vehicle era as well as it was in the STS era. We feel there is limited potential for a cost competitive high-tech expendable approach to be achieved. As a consequence, aeroassist research technology should be pursued vigorously. Generic R&T in low cost expendable upper stage technology should be avoided. Response to good original ideas that have potential of reaching the cost improvement criteria identified would be, of course,appropriate. The possibility of multi-year contracting for expendable vehicles should be explored. Success in these areas could impact our preference for reusable vehicles.

5.2 SCENARIO 2 VEHICLE SELECTION

One of the main changes in the program scenario to be considered in this extension study is the possibility of using a large cargo vehicle on an operational cost basis -- the development is sunk cost on the part of other users. The series of trade studies summarized here developed a definition of the preferred configuration of an OTV designed for use in conjunction with the large cargo vehicle. The key questions to be answered are: What diameter; How many engines; And what array of vehicles in an OTV fleet. The possibilities are sketched in Figure 13. The key discriminating factors are summarized. We found that, for the payloads and cargo bays defined, stage length remains a concern for ground based vehicles. The number of engines selected depends on reliability and spares concerns. We found three in line engines attractive because they afforded a one engine out capability that did not require large engine gimbal angles and increased stage length. The number of members in the vehicle family is a concern that is established by the bottom line -- the various segments of cost.

MAJOR CANDIDATES



FLEET: 1,2 OR 3 SIZES

Objective

SELECT OPTIMUM DIAMETER, NUMBER OF ENGINES AND PROPELLANT LOAD (S) FOR CARGO VEHICLE OTV

Selection Criteria

- KEY FACTORS
  - LENGTH & TRANSPORTATION CHARGE
  - RELIABILITY & MISSION LOSS COST
  - SPARES & EXPENDABLES
  - FAMILY SIZE VS. DDT & E AND OPERATIONS
- BOTTOM LINE: INVESTMENT, OPERATIONS & TOTAL COST

Figure 13 Cargo Vehicle OTV Options

The summary results of our cargo vehicle trades are shown in Figure 14. The details backing up this summary are included in Volume IX. The engine trade results are tabulated. This cost analysis includes engine spare requirements, manifested launch cost, and mission loss cost. The dominant goals are to keep the configuration short, and to keep the configuration reliable. The best net situation is 3 engines for a cargo vehicle concept. 2 engines remains the preferred space based concept, but the best evolutionary concept appears to stay with 3 engines in the era where a no-DDT&E cargo vehicle exists.

The bar charts in Figure 14 show life cycle cost in 1985 and discounted dollars for configurations with 15 foot and large cargo vehicle diameters. The problem with 15 feet is that the configurations are long. The problem with cargo bay diameters is returning the whole vehicle in the ground based mode if it has to come back in the STS cargo bay. These data indicate that it is

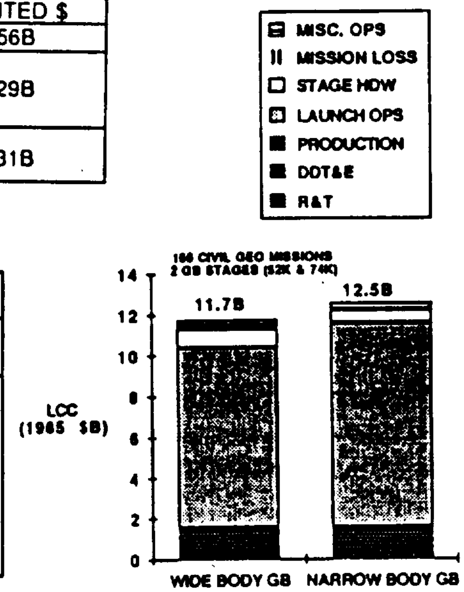
FLEET COMPOSITION

PROPELLANT CAPACITY	FLTS/STG	TOTAL LAUNCH COSTS	
		CONSTANT $	DISCOUNTED $
74K	160	$8.76B	$3.56B
74K 60K 50K	56 13 91	$8.32B	$3.29B
74K 52K	65 95	$8.36B	$3.31B

NUMBER OF ENGINES

# ENGINES	COSTS * BASED ON 160 MISSIONS			
	UNITS	LAUNCH	MISSION LOSS	TOTAL
1	REF	REF	REF	REF
2	+32	+532	-596	-32
3	+64	+204	-558	-290
4	+96	+252	-537	-190

* MILLIONS OF 1986 $
$2M AND 10 MISSIONS PER ENGINE
MISSION LOSS IS $160M



WIDE VS NARROW

Figure 14 Cargo Vehicle OTV Evaluation Factors

preferable to disassemble tankage and throw it away if it won't fit in the STS bay rather than use a long configuration. It is doubtful that a no-DDT&E large return cargo capacity would be better if its recurring cost is the projected $15M/flight. These analyses are based on the concept that down rides on the STS are readily available and that the only transportation charges are an up charge for ASE and on-orbit operations charge for disassembly and stowage.

The final trade data in Figure 14 shows that for 160 GEO missions, the basis used for most of our space basing estimates, a two vehicle family is preferred. We elected to go with the 74/52 family rather than the 74/50 family because there is virtually no cost discriminator, and fewer stages in the inventory results in a simpler operation.

The L/D selected for the OTV aeroassist device has a significant impact on OTV weight, performance and cost effectiveness. We extended our research into the selection of the optimum L/D for the OTV, and have succeeded in validating our recommendation of an L/D of 0.12. The minimum requirement of L/D is to provide maneuver capability adequate to control aeroassist maneuver exit apogee accurately in the face of expected navigation tolerances and variations in upper atmosphere density. An additional consideration exists -- the possibility that proper use of a higher L/D could ease aerobrake design requirements in aerodynamic heating and deceleration g-level, and result in a lower weight. These possibilities were investigated. In prior study phases, it was established that energy savings resulting from performing a part of the geostationary return plane change is not beneficial, so this possibility was not investigated further.

We have run a large number of control authority test cases using a four degree of freedom simulation of our lifting aerobrake control scheme. Aeromaneuver passes through fourteen STS measured atmospheres, incorporating various entry dispersions generated by guidance and navigation errors, were simulated for various candidate aerobrakes. The table on the left of Figure15 summarizes some of the results. Excellent apogee altitude control is exhibited by L/D down to 0.08 -- 0.06 is beginning to become inadequate. As a result of these studies and companion studies by NASA and other contractors, we feel confident that an L/D of 0.12 is adequate to control the aeropass maneuver.

Although L/D = 0.12 is adequate for control purposes, we also investigated whether a higher L/D of 0.30 could result in a lighter brake due to an alleviated heating or loading environment. The upper table on the right side of Figure 15 compares the JSC rigid brake flown at various altitudes in the control corridor. When flown as high in the corridor as control requirements permit, the column labeled 0.3(+), heating rate was reduced, total heat was increased, and peak g-load was reduced. When flown low in the corridor, the column labeled 0.3(-), the opposite changes were observed. Tile weight increases as aeromaneuver altitude is lowered, since the impact of total heat

CONTROL AUTHORITY

L/D	NO. OF CASES	EXIT APOGEE CONTROL (STD DEV-NMI)
0.06	12	415
0.08	20	18.1
0.12	28	12.4
0.15	12	11.6

L/D = 0.12 RECOMMENDED

PRELIMINARY RESULT ON MARS MISSION IS 0.1> L/D < 0.2 PROVIDES ADEQUATE CONTROL AUTHORITY

L/D = 0.12 VS L/D = 0.30

RIGID BRAKE L/D	0.3(+)	0.12	0.3(-)
HEAT FLUX (BTU/FT²/S)	27.8	31.6	36.0
HEAT LOAD (BTU)	4743	3923	3648
TILE THICKNESS(In)	0.87	0.78	0.74
PEAK G LOAD	2.7	3.6	5.37
TILE WT (Lb)	1597	1432	1359
SUBSTRU WT (Lb)	2155	2239	2469
TOT BRAKE WT (Lb)	3752	3671	3828

FLEX BRAKE L/D	0.12	0.30
BRAKE DIA (Ft)	44	50
W/C_DA (PSF)	8.0	7.1
HEAT FLUX (BTU/FT²/S)	25.8	28.8
PEAK G LOAD	3.4	3.8
TILE WT (Lb)	127	118
FLEX WT (Lb)	874	1237
STRU WT (Lb)	812	837
TOT BRAKE WT	1813	2192

Figure 15 L/D Evaluation

on insulation requirements is dominant. Structural weight increases as aeromaneuver altitude is decreased, due to the increasing g-loading. Our data shows a weight optimum very near the center of the corridor -- there appears to be no weight benefit from increased L/D. In the case of the flex brake, as shown in the table in the lower right of Figure 15, the dominant factor is the increased diameter of the aeroshield that results from the wake impingement issue on our relatively long "thrust axis parallel to the aerodynamic axis" configuration. Again the clearly superior approach, by a larger margin, is the lowest L/D acceptable from the control point of view.

We recommend incorporating an aeroassist device into the OTV that has a 0.12 L/D. This selection will provide adequate aeromaneuver control, results in a less severe total heating environment, and yields a lighter aerobrake design. The possible adverse consequence of this approach is that it provides less margin for possible growth in atmospheric uncertainty and guidance and navigation dispersions. It is our opinion that these parameters will be well understood before the design is committed to hardware, and if an increase becomes warranted, it should be incorporated at the time it is confirmed. The principal sensitivity issue is as follows. There are, at this point, uncertainties in the aerothermal environment that will become better understood after the aeroassist flight experiment is flown, and still better understood as operational flight experience is gained. The first flight aerobrake will be flown with conservatisms in design that will protect against these uncertainties -- for example larger diameters and thicker insulation. Our data indicates that the low L/D design will show a smaller weight penalty to accommodate these uncertainties than will the higher L/D design. From this point of view, the low L/D design is to be preferred.

The conceptual design of the OTVs selected for use in conjunction with the cargo vehicle is illustrated in Figure 16. The smaller unmanned vehicle has a 52,000 propellant capacity. Cylindrical propellant tanks with square-root-of-two domes were selected to fit into the 25 foot diameter of the nominal cargo vehicle payload shroud. A larger cargo diameter, sufficient to support spherical tanks, would be beneficial due to the resulting lower tank gauges. The forward ends of the LH_2 tanks (not shown) and LO_2 tanks are placed at the same station. The tank diameters are selected so the three in line engines can be mounted between the LO_2 tank bottoms and the heat shield when the nozzles are retracted, while the LH_2 tanks extend as closely as possible to the aerobrake. The central core, including the center section of the aerobrake, is 14.5 feet in diameter, so it can be returned to earth in the 15 foot diameter STS cargo bay. The same materials as were used in the 1984/85 study configurations were selected. Aluminum lithium tanks, graphite epoxy cool structure and graphite polyimide hot structure was used. The 32 foot diameter aerobrake uses shuttle tiles for its 14.5 foot diameter center section and engine doors, while the outer flexible section is the Nicalon, Q-felt and RTV sealed NEXTEL blanket. Propellant tanks are expended or retrieved on a Shuttle space available basis. Avionics are packaged on the structural bulkheads at the forward end of the vehicle. Trusswork provides the central structural core. This configuration is only 19.7 feet long, and manifests efficiently with payloads.

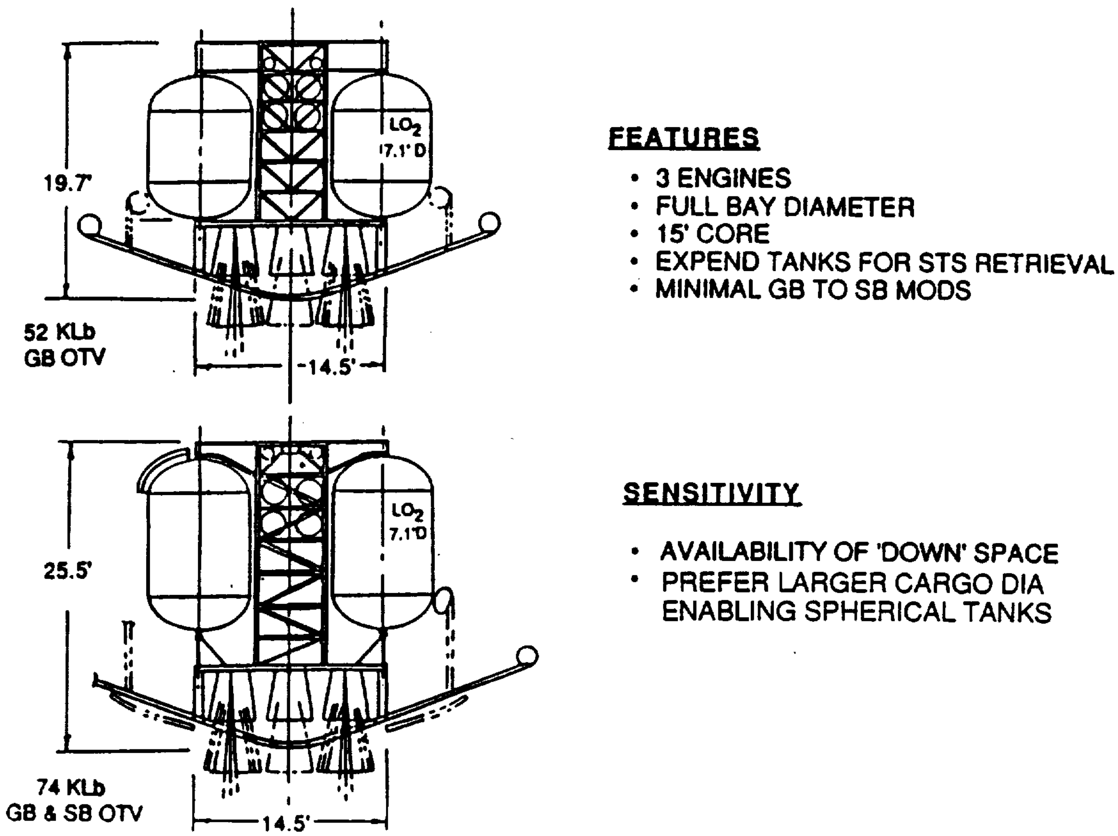


Figure 16 Cargo Vehicle OTV Recommendation

The propellant capacity of the large man rated configuration is increased to 74,000 pounds to enable performance of the 12,000 pounds up, 10,000 pounds down Manned Geo Sortie and GEO Shack Logistics missions. This increased size is achieved by stretching the propellant tanks at the same diameter. The longer stage and spacecraft retrieval combine to require use of a 38 foot diameter aerobrake. Total stage length increases to 25.5 feet. Otherwise, the configuration is essentially similar to the smaller unmanned vehicle. This stage can be extended to space based service by deleting the SOFI insulation on the hydrogen tanks and adding more MLI, adding meteoroid protection, and adding engine quick disconnects and other space base servicing aids.

The pertinent sensitivities associated with these vehicles are indicated. If down space were not readily available as assumed, the cost of ground basing these configurations would escalate -- making space basing more attractive. As previously noted, a cargo bay large enough to accommodate spherical tanks would make the vehicle lighter and result in lower transportation charges to perform the mission model.

5.3 ALTERNATIVE VEHICLE ANALYSES

We tested the possibility that some of the mission scenarios could justify additional members to the OTV family just identified. Our initial thought was that the SDI mission in Scenario 4 might justify a storable propellant selection, since the mission velocity requirements were so low. As it turned out, the mission weights were so high the higher I_{sp} continued to be preferred. We did investigate a smaller, 40,000 pound propellant capacity stage that could be used to perform the indicated mission array instead of the 52,000 pound stage already in the family. We found that a crossover of 420 missions would justify the additional DDT&E. Therefore, Scenario 4 (SDI missions) or Scenario 5 (Nuclear Waste) in conjunction with the smaller missions in the model could justify development of the additional stage size.

We also investigated the use of a large, 240,000 pound propellant capacity stage to perform the very large missions in Scenario 5, rather than segmenting the large GEO mission and performing the large lunar and planetary missions with multi-stage, propellant module approaches contrived from the stage elements already identified. We found that the development of a very large stage was not justified.

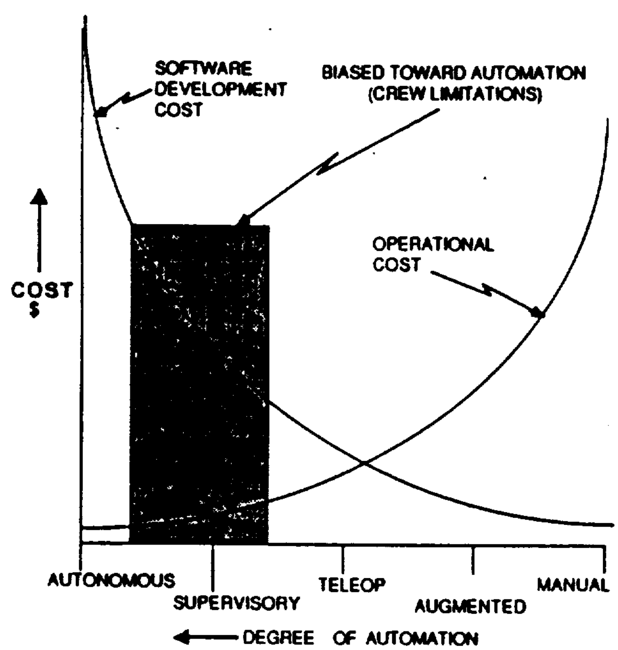
5.4 OPERATIONS ALTERNATIVES

The degree to which EVA operations will figure in OTV space basing operations and the most effective means for performing OTV flight operations in proximity to the Space Station are two of the more significant operations issues examined during this extension study. The EVA versus IVA issue bears on the balance between space station crew utilization and the cost of software and equipment that would allow space based OTV operations to be conducted with a minimum of participation on the part of the limited space station crew. The candidates investigated include the spectrum from primarily EVA activity to remote manipulation with an IVA operator to automated operation with only manned supervision. EVA operation normally requires two EVA crewmen and an IVA operator at all times when there is a crewman outside. Remote manipulation involves one fulltime crewman. Automated operation supervision would allow an operator to manage more than one task simultaneously. There is a clear trade between development cost, operational cost and crew dedication.

We also investigated flight operations that must be conducted in close proximity to the space station. The candidates investigated were: (1) Adding OTV systems that would enable 'driving' up to space station docking with the OTV; (2) Adding limited systems to both OTV and OMV that would enable them to act as a total unit capable of achieving a space station docking approach; And (3) A technique involving separating OTV and any returning payload so the OMV could dock to the OTV payload interface, or to the separated payload at the OTV interface, and perform separate docking approaches to the space station totally under control of the OMV. The criteria for judging these approaches include vehicle complexity, operations complexity, and cost considerations.

Figure 17 illustrates the trade between operational and developmental costs that exists as the OTV maintenance concept shifts from EVA towards continually more automated operations. This comparison is based on our experience that was gained from IR&D and contract activities involving our Space Operations Simulation and Artificial Intelligence laboratories. It is clear that a cost optimum exists where no EVA is involved in normal operations. The appropriate degree of automation will probably fall short of only supervisory control. In addition to this cost oriented comparison, we laid out objective and subjective comparisons of the operational attributes of the various approaches and scored them. The scoring results indicated that a proper balance would probably lie on the fully automated side of IVA/Remote operations, rather than the EVA side.

EVA / IVA



CONCEPT	SCORE
EVA	41
IVA / REMOT	75
AUTO	67

PROX OPNS REQUIREMENTS

OTV CANDIDATE
- EXPAND ACS SYSTEM (2 CLUSTERS)
- ADD FULL COLD GAS SYST (4 CLUST)
- ADD SPACE STATION DATALINK

OTV / OMV CANDIDATE
- EXPAND ACS SYSTEM (2 CLUST)
- ADD LIMITED COLD GAS (2 CLUST)
- PROVIDE OTV / OMV CONTROL I/F

OMV CANDIDATE
- SEPARATE OTV AND S/C
- PERFORM SEPARATE PROX OPNS

Figure 17 Operations Evaluation

In the proximity operations arena, we identified the changes that would have to be made to baseline OTV and OMV designs to accommodate the three major proximity operations candidates identified. Only in the third case shown in Figure 17 were no system changes required. This approach does involve more operations and more operations cost than the other two. We, representing the OTV interest, would prefer this option because it involves no developmental impact on the OTV program. The best approach requires participation of all involved parties: OTV; OMV; and Space Station.

We recommend that no EVA activity be included in normal OTV operations at the space base for the reasons cited, although EVA contingency backup of all operations is necessary. Initial capability probably should include less automation than the ultimate system, to minimize the cost and risk involved with getting started.

The OTV program would benefit from conducting all operations in proximity to the space station with the OMV, but this may not be the overall best approach. We recommend that an OTV / OMV / Space Station working group be constituted to evolve the overall best approach to proximity operations.

6.0 SPACE BASED VS GROUND BASED TRADE

We clearly established that space basing OTV is the preferred operational concept in the STS supported scenario studied last year. We have revisited this issue in the large cargo vehicle supported scenario being investigated in this extension study. A comparative evaluation was conducted on the basis of the 160 civil GEO missions in the Scenario 2 mission model.

In the ground based scenario, all missions were launched on a large cargo vehicle, one mission per flight, with launch charge based on the STS charge algorithm (3/4 length or weight load factor results in a full launch cost charge). This ground based scenario reflected our 25 foot diameter OTV for ascent, and a down volume restricted to the 15 X 60 foot orbiter bay. Any tankage that could not be packaged for retrieval in this volume was discarded, and added to the build cost for the next flight. One retrieval per STS flight was assumed, with the only retrieval charge being for any retrieval ASE required.

In the space based scenario, the same 160 civil GEO missions were launched from a space base. The remaining missions in the Scenario 2 mission model were assumed to continue to be ground based. Propellant 'hitchhiking' was assumed feasible with no transportation charge to the OTV program for the hitchhiked propellants. Cost of the hitchhiking system, propellant tanks and operations, were charged to the OTV program. Space Station support to the OTV program was charged to OTV. OTV flight operations when away from the Space Station were assumed to cost the same when either ground or space based.

A full cost assessment was evolved. The major sensitivity factors investigated were launch vehicle cost, accommodations acquisition cost, hitchhiking efficiency, and cargo vehicle replacement cost. Evaluation criteria included discounted and non-discounted life cycle cost , cost per flight, and non-cost factors. Some of the non-cost factors that influence the desirability of acquiring a space based OTV capability are as follows:

1) <u>Launch/Transfer Coupling</u>: Space basing decouples the launch vehicle and its associated prelaunch and flight operations from the equivalent operations associated with the Orbital Transfer Vehicle. One benefit of this decoupling is that any launch vehicle (Shuttle, Titan IV, or Ariane) can provide payload transportation to LEO with OTV providing deployment to mission orbit. This is likely to be attractive to a certain segment of customers. On the other hand, the time from spacecraft rollout at the factory to on orbit operation is likely to be longer. Some customers will prefer space basing, and some will not.

2) Mission Flexibility Impact: Space basing has an advantage because it can support buildup of missions that are larger than one launch vehicle can carry. This would be important in the early mission years if launch capability were limited to existing shuttle capability. If a large cargo vehicle were developed, the capability would be advantageous when the nation undertakes the anticipated lunar base and manned Mars initiatives. Conversely, ground basing has a significant performance advantage for high inclination missions that would require large orbital turns if launched from the currently envisioned Space Station.

3) Frequency of Ground Launch: Higher load factors are expected for launches supporting Space Station since propellant hitchhiking will fill capability remaining after 'hard' payloads have been manifested. Fewer launches means less contamination of the launch area environment from SRB and other exhaust products, as well as less possibility of a catastrophic failure of the launch system. This is a distinct advantage for the space based system.

4) OTV Logistics: The space based system requires neither OTV transportation from ground to LEO nor partial OTV disassembly for return to the ground in the orbiter bay on every mission. However, the space based system must be maintained under what are currently unfamiliar conditions. The cost of maintenance operations has been estimated and reflected in our assessments, but there remains an element of risk in space based operation that must be considered in the decision process.

5) OTV & Spacecraft Checkout: Space basing requires development of a capability to check out systems in the space environment. Once developed, this capability enables checkout of both spacecraft and OTV after passage through the launch environment, which is generally the most severe environment either will encounter. Coupled with a maintenance capability, this offers a potential for recovering from infant mortality, and occasionally achieving a significant cost benefit.

6) Launch Cost Sensitivity: The cost of delivering 'hitchhiked' propellants to the Space Station is assumed to involve only the cost of the hitchhike system (tanks and operations), and not to involve transportation charges. This tends to decouple the cost of OTV operations from launch vehicle cost in the space based mode. If the launch costs escalate, the cost of OTV operations does not escalate in response. On the other hand, the benefit of breakthroughs in launch vehicle technology will not as directly influence the cost of OTV operation.

7) Technology Advance: Space basing potentially offers the dual advantages of enhanced international prestige and the synergisms that can follow the development of new technologies. These benefits are not readily quantifiable, but are certainly not possible without venturing into a new arena. Conversely, if nothing is ventured, nothing is lost. Eliminating the new space based technology reduces cost and schedule risk for most users.

It is clear that both operational modes have significant advantages. If a space based capability is developed, we do not believe it should supplant a ground based capability -- it would be desirable for both to coexist throughout the foreseeable future. There are significant advantages to possessing the space based OTV launch capability that can justify the developmental investment.

The key economic issues that will establish the economic feasibility of space basing OTV are: The cost advantage resulting from fully utilizing the large cargo vehicle lift capability by filling out the cargo manifest with 'hitchhiked' propellants; The cost of acquiring OTV accommodations at the space base; And the benefit of reducing launch vehicle use that results from the space based operational mode.

We conducted an evaluation to establish what portion of OTV propellant requirements could likely be provided by the 'hitchhike' concept. Historically, shuttle manifesting analyses have shown that a 75% load factor is to be expected. We applied this factor to the large cargo vehicle, conceived a discrete array of tankage to use the leftover lift capability, and investigated planned cargo vehicle and OTV flight schedules to establish the resulting 'hitchhike' capability. We found that 70% of the unused space could be utilized. The fuel carrying capability is compared with the OTV requirement in Figure 18. It appears that 63% of OTV propellant requirements can be met by the concept. Our ground rules state that there is no transportation charge for hitchhiked propellants, but that the system of tankage and operations is to be charged. These ground rules are reflected in subsequent analyses, and the quantity of propellants available has been treated parametrically.

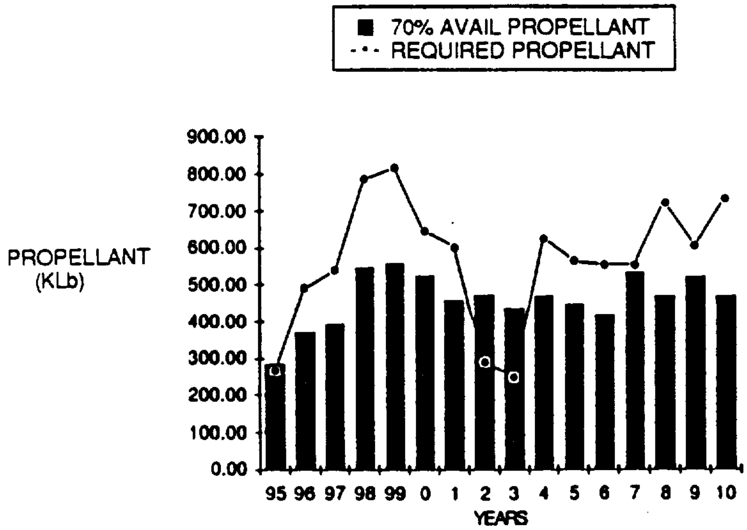
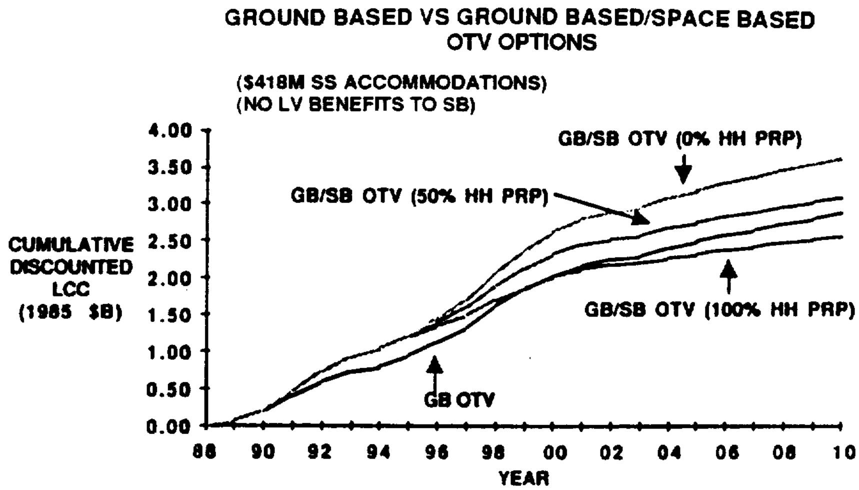


Figure 18 Availability of Hitchhiked Propellant

We conducted an evaluation of the possible cost of OTV accommodations at the Space Station. This item is discussed in more detail in Volume IX. It is believed that the cost of initial space based OTV accommodations can be reduced from the $936M estimated last year to in the neighborhood of $418M by sharing the cost of accommodations with OMV, reflecting more realistic software development cost, down sizing the hangar and propellant farm, and launching elements with the lower cost large cargo vehicle. We also believe the space based mode should be given credit for a reduction in launch vehicle replacement cost resulting from fewer launch vehicle uses. We anticipate 52 fewer large cargo vehicle flights will be necessary to support the space based scenario than are required to support the ground based scenario, since the launch vehicle is more efficiently manifested. The 52 flights represent 25% of the reusable booster stage's design lifetime, and thus a $400M prorated replacement build cost savings.

Figure 19 shows a typical spread of space based program cost compared with ground based program cost. This particular set of space based data reflects: Space Station accommodations costs at $418M; Crediting the space based program with the booster build cost benefit associated with fewer large cargo vehicle launches; and 0%, 50%, and 100% of space based OTV propellant requirements provided by 'hitchhiked' propellants. The associated cost per flight data is also tabulated. This type of data were generated for a parametric set of conditions, and used to bound the range of possible space based programs.



COST PER FLIGHT

GBOTV	$63.4M
GB / SB 0%	$77.6M
GB / SB 50%	$60.6M
GB / SB 100%	$43.6M

Figure 19 Typical Discounted Cost: Ground Based vs Space Based

Figure 20 summarizes the effects of several parameters influencing the economic viability of space based OTV operations. The cost of a large cargo vehicle flight is fixed at $70M for this figure, and the data reflects conducting the 160 civil GEO missions in the Scenario 2 mission model from the space base. Conducting more missions from the space base would provide more cost benefit. The data is shown on carpet plots that depict the life cycle savings (or loss) associated with conducting the 160 missions from the space base as opposed to conducting them with a purely ground based program. The two carpets to the left depict the cost picture in constant dollars, the two to the right reflect discounted dollars. Each carpet depicts variation of two space basing cost parameters: Space base OTV accommodations acquisition cost; And the percent of OTV propellant requirements that are provided by 'hitchhiked' propellants. Maximum hitchhiked propellants and lowest accommodations acquisition cost yields the highest cost advantage for space basing. The upper carpet in each pair summarizes the GB/SB cost comparison with the launch vehicle build benefit, the lower shows the same comparison without this launch vehicle benefit. The position where we feel the program stands is indicated with the circled data point.

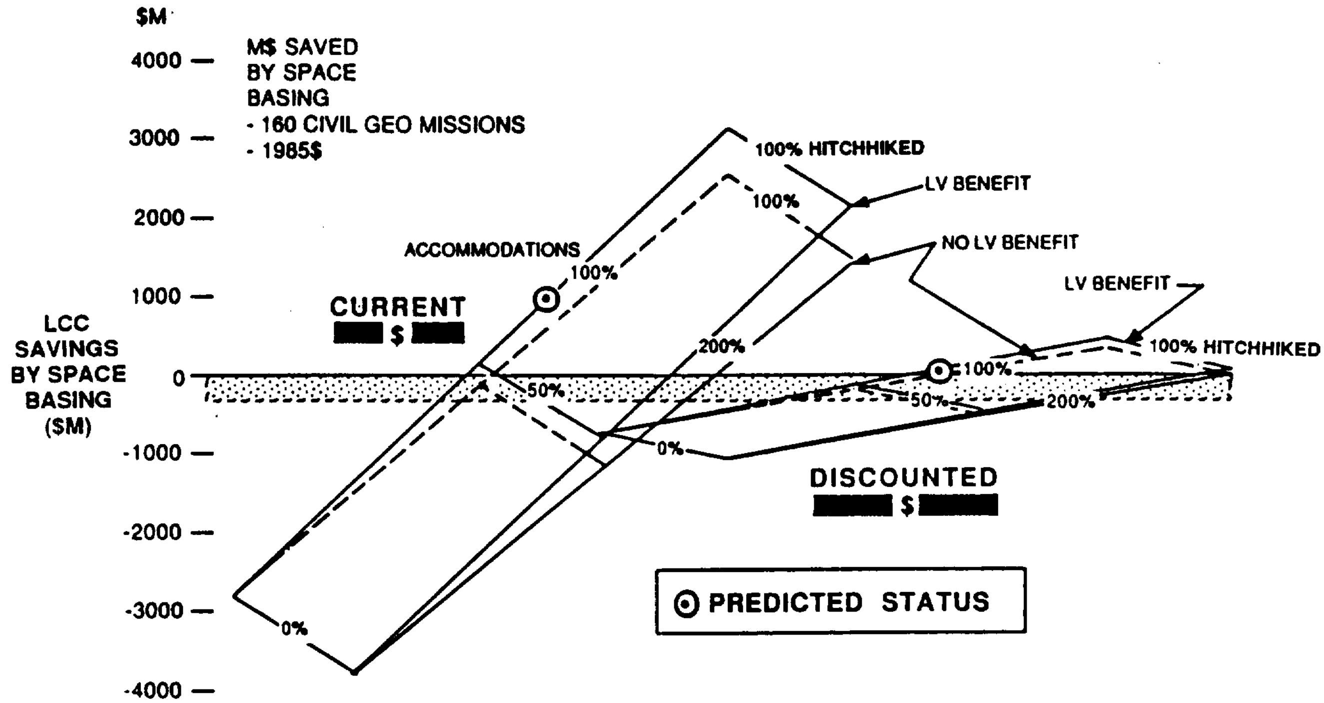


Figure 20 Space Basing Cost Sensitivity

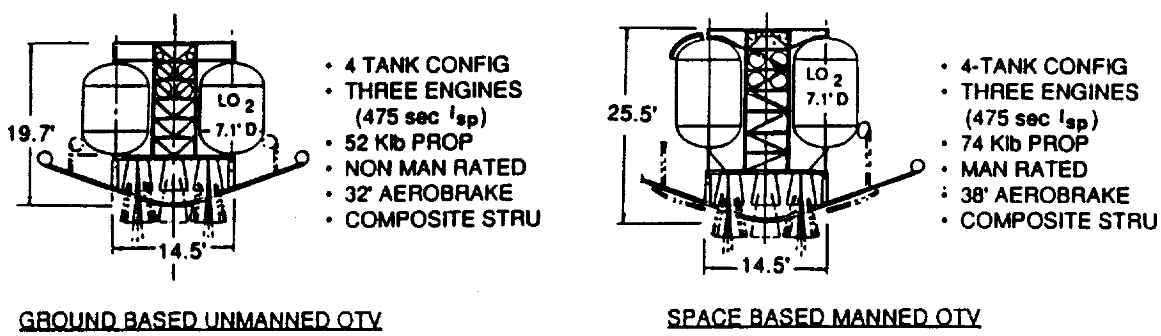
It is clear that it is far more difficult to achieve economical space based operations on a discounted cost basis than it is with constant dollars. We believe the space based program will save $1B over the 160 flights in constant dollars, while the equivalent circumstances will show no net difference in discounted dollars. In all cases, operations costs will be reduced, once the development cost has been written off.

We recommend developing a space based OTV launch capability. It is difficult to show a cost savings for space basing on a discounted cost basis. Consequently, it is important to keep initial acquisition cost as low as possible, and to maximize the efficiency of the 'hitchhiked' propellant concept. Once the capability is acquired, operational cost is reduced, and other operational benefits become available. We believe the capability is important for the nation, and that it is worth the investment.

7.0 CARGO VEHICLE BASED OTV PROGRAM

7.1 BASELINE PROGRAM DESCRIPTION

We have concluded that the preferred Orbital Transfer Vehicle program in the era where a large cargo vehicle is available and Scenario 2 missions are to be performed will be as summarized in Figure 21. It will comprise two types of orbital transfer vehicles. A three in-line engine, four side-by side tank, unmanned, ground based vehicle with a 52,000 pound propellant capacity will support initial missions. This vehicle will be used throughout the operational period. A generally similar manned, space based vehicle with a 74,000 pound propellant capacity will be made operational as soon as it can be supported by the Space Station. All manned missions will be launched from a space base, but the space based vehicle can be launched from the ground as well. Its initial mission will be ground based -- returning to residence at the Space Station upon return.



PROGRAM ASSUMPTIONS
- DECISIONS BASED ON REV. 9 SCENARIO 2 OTV MISSION MODEL
- ONLY TWO CONFIGURATIONS REQUIRED
- 1995 IOC FOR GROUND BASED SYSTEM, 1996 FOR SPACE BASED
- MAN-RATED VEHICLE CAN OPERATE FROM GROUND AS WELL AS SPACE WITH MINIMAL CHANGES

Figure 21 Nominal LCV OTV Configurations

The major cost and schedules associated with the OTV configurations in Figure 21 are summarized in Figures 22 through 24. Figure 22 shows a spread of the major cost elements involved in capturing the Scenario 2 DoD and Civil Mission Model. The total acquisition cost for R&T, DDT&E for both ground and space based stages and space base accommodations, and vehicle and accommodations production is \$2B. The total cost of operations through FY 2010 is \$22.1B.

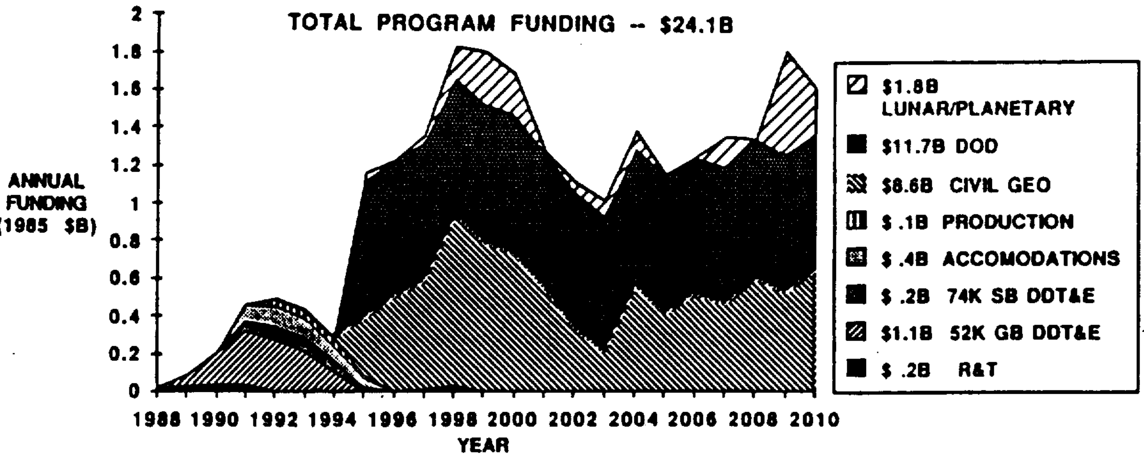


Figure 22 Nominal LCV OTV Program Funding

The development schedule for the ground based OTV is summarized in Figure 23. An ATP on January 1, 1989 supports an Initial Operational Capability in January 1995. A space based OTV program ATP in January, 1990 (Figure 24) supports an Initial Operational Capability in January 1996. It is currently anticipated that this is the earliest space based operational capability that can be supported, and that an initial capability near the turn of the century would be more likely to occur.

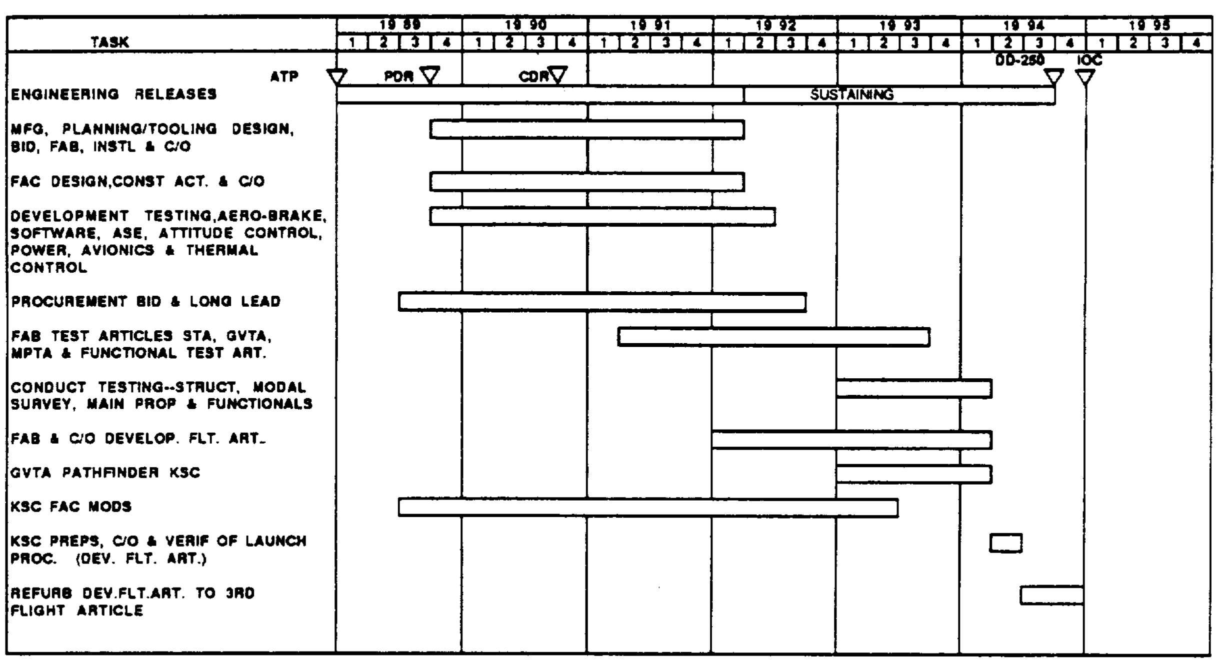


Figure 23 Ground Based OTV Schedule

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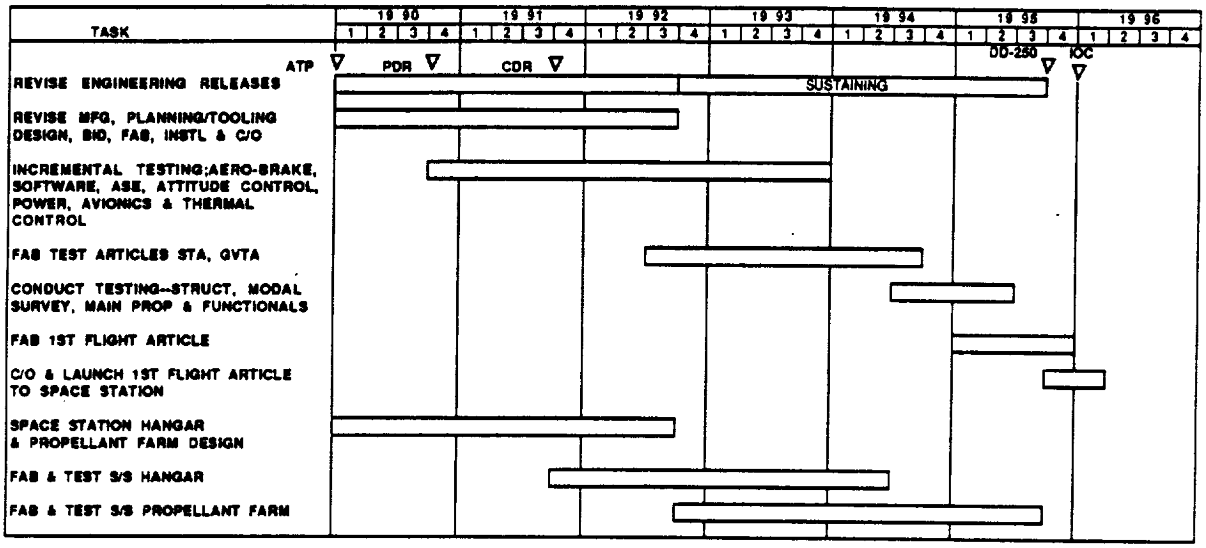

Figure 24 Earliest Capability Space Based OTV Schedule

7.2 PROGRAM SENSITIVITIES

The major characteristics of the five mission scenarios investigated are shown in Figure 25. Scenario 1 does not present a driver for space basing, particularly because it contains no manned GEO missions. Scenario 2 justifies the nominal OTV program just discussed. Scenario 3 requires nothing different from the OTV program, assuming that the limited SDI mission activity is not multiple-launched on OTVs. Scenario 4 justifies a specialized OTV directed at the low mid-inclination and other DoD traffic. Scenario 5 justifies a specialized nuclear waste OTV which has a strong possibility of being able to perform selected DoD missions more effectively as well. This scenario also requires build-up of multi-stage OTVs at the space base and requires that more OTVs be resident in space.

	MAJOR CHARACTERISTIC	IMPACT ON OTV PROGRAM
SCENARIO 1	NO MANNED GEO PRIOR TO 2010	NO SPACE BASE DRIVER
SCENARIO 2	A BALANCED, BUT ACTIVE PROGRAM	NOMINAL
SCENARIO 3	ADDITION OF LARGE PLANETARIES	MINIMAL IMPACT ON OTV PROGRAM
SCENARIO 4	HEAVY DOD TRAFFIC TO MID INCLINATION	SPECIALIZED 40K OTV
SCENARIO 5	AGGRESSIVE PROGRESS TOWARDS 50-YEAR INITIATIVES	• MULTI-STAGE BUILDUP AT SPACE BASE • SPECIALIZED NUCLEAR WASTE OTV

Figure 25 Mission Model Impact On OTV Program

The major characteristics of the five launch scenarios investigated are shown in Figure 26. It is uncertain how much STS growth can be expected. If the OTV program is limited to the use of a shuttle with a 65,000 pound (or less) payload capability, many of the early missions in all the models will involve multiple launches with attendant operational problems. In this scenario, space basing has even more virtue than in the cargo vehicle supported era we concentrated on in this extension study. The large cargo vehicle without retrieval capability results in the recommended OTV program previously discussed. The preferred OTV configuration for this case has been shown to be the wide body configuration. This approach leads to the operational complexities cited in the ground based case. We would, of course prefer the wide-body retrieval capability if only its operational cost is involved. The justification of the development cost of this capability is beyond the scope of this OTV study. Propellant hitchhiking and scavenging are the economic savior of the space based OTV concept. This justification is real, but will likely prove upsetting to the users that are paying the launch bill. They would likely prefer to share in the cost benefit. The impact of STS II on OTV program selection appears to be minimal.

	MOST SIGNIFICANT FEATURE	IMPACT ON OTV PROGRAM
STS GROWTH	• HEAVIER LEO CARGO • ACC 'UP' VOLUME	ENHANCES SPACE BASED OTV PROGRAM
LARGE CARGO VEHICLE (NO RETRIEVAL)	LOW COST TRANS-PORTATION TO LEO	GND BASED OPS COMPLEX - VEHICLE DISASSEMBLY - EXPENDABLE TANKS
LARGE CARGO VEHICLE (WITH RETRIEVAL)	LARGE OTV RETRIEVAL CAPABILITY	ENHANCES GROUND BASED OTV PROGRAM
PROPELLANT HITCHHIKING & SCAVENGING	NO PROPELLANT TRANSPORT CHARGE	PROVIDES ECONOMIC JUSTIFICATION FOR SPACE BASING
STS II	LOW COST MANNED LAUNCH	MINIMAL

Figure 26 Launch Vehicle Impact On OTV Program

Four possible space basing scenarios are identified in the Figure 27. With no space based support, missions that cannot be launched from the ground on a single flight require complex Orbiter support operations. For example, launching a manned GEO mission would require two current capability Orbiter launches on one week centers with Orbiter supported on-orbit mission assembly. With a 65,000 pound capability STS, the occurrence of this problem is frequent. With a large cargo vehicle, the problem will eventually occur. Space tending with the Space Station would ease this problem, but the timing would still be constrained unless the ability to top propellants were provided as a part of the space tending package. This approach does not enable acquiring the potential benefit of the hitchhiked propellant concept. The nominal space based approach achieves all the operational benefits previously discussed, and mitigates the cost of this capability with the benefit of hitchhiked propellants. If space station were delayed until the manned missions are scheduled, the impact would be: The large early missions would require either complex ground based operations or more payload segmentation; And the operational base that is required to pay off developmental cost would be beyond the horizon of this study.

	MOST SIGNIFICANT FEATURE	IMPACT ON OTV PROGRAM
NO SPACE BASE SUPPORT	—	REQUIRES COORDINATED RAPID L/V TURNAROUND AND COMPLEX ORBITER SUPPORTED LEO OPERATIONS
SPACE TENDING	SUPPORTS LEO MISSION ASSEMBLY	DECOUPLES L/V AND OTV OPERATIONS AND PROVIDES LEO OPNS SUPPORT
NOMINAL SPACE BASING	AVAILABLE FOR LARGE UNMANNED GEO	ENABLES: - SUPPORT OF ALL LARGE MISSIONS - PERMANENT OTV SPACE RESIDENCE - 'HITCHHIKE' BENEFITS (FEWER L/V LAUNCHES)
DELAYED SPACE BASING	AVAILABLE FOR MANNED GEO	EARLY LARGE GEO MISSIONS REQUIRE COMPLEX LEO OPNS

Figure 27 Space Basing Impact On OTV Program

Development of the reusable OTV is economically justified, even in the most modest projected mission scenarios. We believe that, even though it is difficult to justify on a discounted life cycle cost basis, the lower operational cost of space based OTV missions and the ancillary operational benefits justify investment in space basing. Further Phase A effort should be directed at identifying an initial OTV that will be useful whether or not a large cargo vehicle program is initiated in the near future, and one that has a good growth path to space based capability. We believe the key to meeting this objective is to develop a concept that can fly in an Aft Cargo Carrier or a large cargo vehicle with minimal design penalty. After this concept is delineated, an extended Phase B should optimize the concept, and a full scale development directed at achieving a mid 90's initial operational capability should be undertaken.

GLOSSARY

ACC	Aft Cargo Carrier
ASE	Airborne Support Equipment
ATP	Authority to Proceed
BTU	British Thermal Unit
CDR	Critical Design Review
c/o	Checkout
DD-250	Final End Item Acceptance by the Government
DDT&E	Design, Development, Test, & Engineering
DoD	Department of Defense
ETR	Eastern Test Range
EVA	Extra Vehicular Activity
GB	Ground Based
GEO	Geostationary Orbit
GVTA	Ground Vibration Test Article
HEO	High Earth Orbit
HH PRP	Hitchhiked Propellant
IOC	Initial Operational Capability
IR&D	Independent Research and Development
Isp	Specific Impulse
IVA	Intra Vehicular Activity
L/D	Lift to Drag Ratio
LEO	Low Earth Orbit
LCV	Large Cargo Vehicle
L/V	Launch Vehicle
JSC	Johnson Spaceflight Center
KSC	Kennedy Space Center
MLI	Multi-Layer Insulation
MPTA	Main Propulsion Test Article
MSFC	Marshall Space Flight Center
OML	Outside Mo.ld Line
OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
PDR	Preliminary Design Review
R&T	Research and Technology
R/T	Round Trip
RTV	Room Temperature Vulcanizing Sealant
SB	Space Based
SDI	Space Defense Initiative
SOFI	Spray on Foam Insulator
SRB	Solid Rocket Booster
S/S	Space Station
STA	Static Test Article
STAS	Space Transportation Architecture Study
STS	Space Transportation System
W/C_DA	Ballistic Coefficient, pounds/square foot